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RESEARCH MEMORANDUM

PERFORMANCE EVALUATION OF REDUCED-CHORD ROTOR BLADING AS APPLIED TO J73 TWO-STAGE TURBINE

V - EFFECT OF INLET PRESSURE ON OVER-ALL PERFORMANCE AT DESIGN SPEED AND INLET TEMPERATURE OF 700° R

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Previous investigations conducted on the multistage turbines from the J73 turbojet engine utilizing both standard and reduced-chord rotor blading have indicated peak efficiencies of over 90 percent when investigated with uniform turbine-inlet conditions of 35 inches of mercury absolute and 700° R. Furthermore, high efficiencies were obtained with both turbine configurations over wide ranges of speed and pressure ratio. Because of the comparable performance of the two multistage turbines, the reduced-chord configuration can be utilized profitably to obtain a considerable saving of turbine component weight, provided no adverse effects of Reynolds number interfere with the performance of the short-chord blades at low turbine-inlet pressure. Accordingly, the reduced-chord multistage turbine was operated at the design speed and at various turbine-inlet pressures from 12 to 40 inches of mercury absolute. At each nominal inlet pressure, the turbine was operated over a range of over-all turbine total-pressure ratios; turbine-inlet temperature was maintained at 700° R.

The results of the investigation indicate that no appreciable effect on turbine over-all performance was observed over the range of turbine-inlet total pressures investigated.

INTRODUCTION

An investigation of the two-stage turbine from the J73 turbojet engine has been conducted at the NACA Lewis laboratory in order to determine the over-all performance characteristics with various turbine rotor-blading configurations and turbine-inlet conditions. The multistage

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[1]The information presented herein was previously given limited distribution.

turbines with both standard rotor blading (ref. 1) and reduced-chord rotor blading (ref. 2) were investigated at inlet conditions of 35 inches of mercury absolute and 700° R and over a range of speed and pressure ratio. Both multistage turbine configurations exhibited efficiencies of over 90 percent at the design operating point and provided high efficiencies over wide ranges of pressure ratio and speed.

Because of the comparable good performance obtained with either the standard or reduced-chord multistage-turbine configurations at an inlet pressure of 35 inches of mercury absolute, and because the reduced-chord turbine represented a considerable saving of turbine component weight as compared with the standard-bladed turbine, the J73 multistage reduced-chord turbine investigation was extended to determine the effect of inlet pressure on this turbine performance. Accordingly, the multistage turbine with reduced-chord rotor blades was operated over a range of inlet pressures from approximately 12 to 40 inches of mercury absolute at design equivalent speed with a constant turbine-inlet temperature of 700° R. A range of over-all pressure ratio was investigated at each inlet pressure. The results of this investigation are presented herein and include tabular data for the convenience of the reader.

SYMBOLS

The following symbols are used in this report:

N rotational speed, rpm

p static pressure, in. Hg abs

p' total pressure, in. Hg abs

p'_x total pressure plus velocity pressure corresponding to axial component of velocity, in. Hg abs

T' total temperature, °R

V velocity

w weight flow, lb/sec

γ ratio of specific heats

δ ratio of inlet-air pressure to NACA standard sea-level pressure, $p'_1/29.92$ in. Hg abs

ϵ function of γ, $\dfrac{\gamma_0}{\gamma_e}\left[\dfrac{\left(\dfrac{\gamma_e + 1}{2}\right)^{\frac{\gamma_e}{\gamma_e - 1}}}{\left(\dfrac{\gamma_0 + 1}{2}\right)^{\frac{\gamma_0}{\gamma_0 - 1}}}\right]$

η_i brake internal efficiency defined as ratio of actual turbine work based on torque measurements to ideal work based on inlet total pressure p_1' and outlet total pressure corrected for whirl $p_{x,2}'$

θ_{cr} squared ratio of critical velocity to critical velocity at NACA standard sea-level temperature of 518.4° R, $(V_{cr,e}/V_{cr,0})^2$

τ torque, ft-lb

Subscripts:

cr critical

e engine

x axial

0 NACA standard sea-level conditions

1 turbine-inlet measuring station

2 turbine-outlet measuring station

APPARATUS AND INSTRUMENTATION

The standard two-stage turbine from the J73 turbojet engine is described in reference 1. The modified turbine, incorporating the reduced-chord rotor blades on both stages, is described in reference 2. The sea-level design conditions as supplied by the manufacturer and the design equivalent conditions are as follows:

Condition	Engine sea-level design, zero ram	Equivalent design
Weight flow, lb/sec	138.7	42.05
Rotational speed, rpm	7950	4041
Inlet temperature, °R	2060	518.4
Inlet pressure, in. Hg abs	201	29.92

The over-all experimental setup used for the subject investigation of the reduced-chord multistage turbine was essentially the same as that described in reference 1 with the modifications to the rotor blading as described in reference 2. A photograph of the experimental installation is presented in figure 1. A schematic diagram of the over-all turbine setup is shown in figure 2(a). Figures 2(b) and (c) show the standard and the reduced-chord rotor blading, respectively, as modified and investigated herein.

The instrumentation necessary to determine the over-all performance of the reduced-chord turbine for this investigation was the same as that described in reference 1. The gas state at the turbine-inlet and -outlet measuring stations was determined at the locations indicated in figure 2(a).

PROCEDURE

Turbine-inlet total pressure p_1' was computed from the average inlet static-pressure readings, the average inlet total temperature, the known annulus area, and the turbine weight flow corrected for the fuel addition. Turbine-outlet total pressure $p_{x,2}'$ was also computed and is defined herein as the static pressure at the discharge measuring station plus the velocity pressure corresponding to the axial velocity of the absolute rotor discharge velocity. This calculated total pressure $p_{x,2}'$ necessarily charged the turbine for the kinetic energy of the rotor-discharge tangential velocity. The method employed in the determination of the design equivalent conditions as previously tabulated and the detailed procedure for calculating p_1' and $p_{x,2}'$ are presented in reference 1.

For the investigation reported herein, the turbine was operated at the design equivalent speed $(N/\sqrt{\theta_{cr,1}} = 4041 \text{ rpm})$, and the inlet pressure was varied from 12 to 40 inches of mercury absolute. If a flight Mach number of 0.8 is considered with an assumed value of 100-percent ram pressure recovery at the compressor inlet, this range of inlet pressure from 12 to 40 inches of mercury absolute corresponds to an equivalent-pressure-altitude range from approximately 41,000 to 15,000 feet, respectively, for a constant compressor pressure ratio of 7, a burner pressure drop of 4 percent, and a turbine-inlet temperature of 2060° R. For all runs, the turbine-inlet temperature was maintained at 700° R. At each nominal turbine-inlet pressure of 12, 16, 20, 25, 30, 35, and 40 inches of mercury absolute, the over-all total-pressure ratio $p_1'/p_{x,2}'$ was varied from approximately 1.4 to 4.0.

Because the majority of the turbine-inlet pressures were less than atmospheric pressure, particular efforts were made to minimize air leakage into the turbine configuration and the test facility. This air leakage was considered significant because relatively small values of leakage may represent a sizable percentage of the total turbine weight flow at the very low inlet pressures. The test facility was, therefore, evacuated, and the air leakage was calibrated by measuring the time rate of change of pressure. The results indicate that the actual leakage values were small, being less than 0.03 pound per second in all cases. The turbine weight flows as presented, however, have been corrected for this leakage.

RESULTS AND DISCUSSION

The over-all performance of the two-stage J73 turbine with reduced-chord rotors is presented in terms of equivalent torque output, equivalent turbine weight flow, equivalent total-pressure ratio, and brake internal efficiency. All performance data were obtained at the design equivalent speed (4041 rpm). The performance parameters presented have been corrected to NACA standard sea-level conditions corresponding to 29.92 inches of mercury absolute and 518.4° R.

The variation of the equivalent torque output $(\tau/\delta_1)\epsilon$ with over-all turbine total-pressure ratio $p_1'/p_{x,2}'$ at the design equivalent speed $N/\sqrt{\theta_{cr,1}}$ and over a range of turbine-inlet total pressure p_1' is presented in figure 3. Any significant trends in these data with inlet pressure lie within the limits of experimental accuracy, so that no definite conclusions can be derived. For all practical purposes, the majority of the data points fall along a single representative curve. The curve corresponds to the torque curve in reference 2 (fig. 6) at the design equivalent speed.

The equivalent turbine weight flow $(w\sqrt{\theta_{cr,1}}/\delta_1)\epsilon$ obtained at the various turbine-inlet total pressures is presented in figure 4 as a function of turbine over-all total-pressure ratio. Again, a single representative curve is appropriate. Stator choking conditions prevailed at over-all pressure ratios above 3.0. The choking value of the equivalent turbine weight flow was 42.35 pounds per second. In this choked-flow region, a maximum deviation of the equivalent turbine weight flow from the mean curve amounted to less than ±0.5 percent of the total weight flow. This measured maximum deviation is half the normal precision obtainable when using the A.S.M.E. flat-plate orifice; and, consequently, any trend in the data with turbine-inlet total pressure is well within the obtainable experimental accuracy. The curve presented in figure 4 corresponds to that presented in reference 2 (fig. 5) for the design equivalent speed. A compilation of the observed torque and weight-flow data as well as other pertinent performance parameters is included in table I for convenience.

Because both the turbine weight flow and the torque output curves (figs. 3 and 4) correlate those in reference 2 at the design speed, it would naturally follow that the brake internal efficiencies η_i as obtained herein would be the same. However, the variation of efficiency with over-all total-pressure ratio presented in reference 2 (fig. 4) at design speed is repeated herein for the convenience of the reader and represents, for all practical purposes, the turbine efficiencies obtained over the range of turbine-inlet pressures investigated. 3212

In summary, then, it may be stated that, at the design equivalent speed and over the range of over-all turbine total-pressure ratios investigated, varying the turbine-inlet total pressure from 12 to 40 inches of mercury absolute has no appreciable effect on the performance of the multistage J73 turbine with reduced-chord rotor blading.

SUMMARY OF RESULTS

From an investigation of the reduced-chord multistage turbine from the J73 turbojet engine at design equivalent speed and over a range of over-all turbine total-pressure ratio, no appreciable effect on turbine performance was observed as the turbine-inlet total pressure was varied from 12 to 40 inches of mercury absolute.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 15, 1953

REFERENCES

1. Berkey, William E., Rebeske, John J., Jr., and Forrette, Robert E.: Performance Evaluation of Reduced-Chord Rotor Blading as Applied to J73 Two-Stage Turbine. I - Over-All Performance with Standard Rotor Blading at Inlet Conditions of 35 Inches of Mercury Absolute and 700° R. NACA RM E52G31, 1957.

2. Schum, Harold J., Rebeske, John J., Jr., and Forrette, Robert E.: Performance Evaluation of Reduced-Chord Rotor Blading as Applied to J73 Two-Stage Turbine. II - Over-All Performance at Inlet Conditions of 35 Inches of Mercury Absolute and 700° R. NACA RM E53B25, 1957.

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TABLE I. - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION OF J73 TWO-STAGE TURBINE WITH REDUCED-CHORD ROTOR BLADING AT VARIOUS INLET PRESSURES

Calculated over-all total-pressure ratio, $p'_1/p'_{x,2}$	Over-all total-pressure ratio, p'_1/p'_2	Over-all total-to-static pressure ratio, p'_1/p_2	Inlet total pressure, p'_1, in. Hg abs	Inlet total temperature, T'_1, °R	Outlet total temperature, T'_2, °R	Engine speed, N, rpm	Weight flow, w, lb/sec	Torque, τ, ft-lb
1.522	1.447	1.568	11.84	701.0	643.2	4713	12.33	266
1.677	1.630	1.746	11.87	714.1	633.0	4709	13.05	392
1.954	1.970	2.077	11.80	702.1	594.0	4713	13.81	564
2.278	2.316	2.487	11.74	702.1	574.1	4712	14.06	701
2.568	2.599	2.878	11.80	702.6	557.5	4712	14.21	799
2.823	2.864	3.259	11.83	702.8	547.0	4713	14.35	862
3.076	3.008	3.664	11.76	703.0	536.5	4715	14.30	922
3.856	3.536	5.368	11.81	701.4	519.7	4705	14.30	1013
1.372	1.319	1.403	15.77	702.1	660.1	4714	15.39	230
1.509	1.432	1.554	15.80	701.8	645.6	4711	16.35	346
1.661	1.626	1.729	15.63	703.1	617.3	4715	17.45	546
1.983	1.949	2.112	15.59	703.5	590.8	4708	18.41	768
2.230	2.224	2.423	15.70	703.1	574.9	4711	18.75	915
2.600	2.667	2.925	15.68	702.7	553.0	4706	18.95	1077
2.856	2.882	3.301	15.68	702.6	542.4	4710	19.01	1157
3.182	3.063	3.849	15.59	702.9	530.5	4704	19.01	1252
3.940	3.629	5.687	15.64	703.2	516.8	4708	19.00	1364
1.397	1.339	1.429	19.75	700.8	656.1	4712	19.59	339
1.625	1.545	1.685	19.70	701.2	628.4	4714	21.46	610
2.053	1.997	2.197	19.75	701.9	588.9	4716	23.27	1021
2.291	2.281	2.551	19.64	701.1	570.4	4707	23.60	1208
2.602	2.602	2.927	19.70	702.1	553.2	4701	23.87	1378
2.813	2.859	3.240	19.70	702.8	542.4	4710	23.92	1476
3.195	3.066	3.870	19.62	702.9	530.3	4713	23.95	1603
3.441	3.275	4.335	19.68	699.6	521.3	4713	23.95	1664
3.923	3.539	5.564	19.64	701.1	514.4	4712	23.85	1740
1.328	1.261	1.352	24.84	701.8	666.5	4733	23.27	303
1.617	1.558	1.678	24.60	704.2	628.4	4720	26.92	753
1.926	1.894	2.043	24.58	702.5	594.6	4716	28.76	1137
2.249	2.216	2.446	24.58	703.4	571.5	4719	29.47	1450
2.740	2.753	3.129	24.53	702.6	544.3	4718	29.80	1778
3.059	3.012	3.627	24.52	703.2	531.6	4725	29.80	1943
3.399	3.268	4.248	24.51	702.9	522.0	4719	29.80	2064
3.888	3.566	5.506	24.50	703.6	514.6	4715	29.90	2163
1.392	1.318	1.423	29.80	701.0	657.3	4715	29.31	467
1.698	1.634	1.771	29.58	701.4	617.0	4721	33.21	1037
2.057	2.019	2.203	29.50	701.4	584.5	4720	34.87	1524
2.391	2.351	2.634	29.48	701.2	564.1	4710	35.61	1870
2.700	2.683	3.068	29.51	701.5	546.1	4717	35.84	2110
3.055	3.017	3.618	29.45	701.3	530.5	4711	35.79	2329
3.496	3.289	4.448	29.40	701.7	521.2	4715	35.79	2500
3.915	3.518	5.583	29.48	701.5	514.6	4716	36.02	2592
1.370	1.301	1.399	34.66	700.3	659.3	4712	33.52	500
1.707	1.640	1.781	34.66	701.8	617.4	4717	38.67	1223
2.030	1.995	2.170	34.41	701.1	585.5	4721	40.59	1749
2.347	2.303	2.574	34.41	700.8	565.6	4717	41.40	2143
2.691	2.695	3.055	34.34	701.3	544.8	4719	41.68	2478
3.130	3.057	3.749	34.30	701.1	528.1	4718	41.75	2768
3.440	3.252	4.320	34.47	701.3	520.8	4721	41.84	2910
3.919	3.520	5.560	34.53	701.4	515.5	4721	41.98	3042
1.419	1.343	1.453	39.56	700.3	653.1	4723	39.37	691
1.725	1.662	1.802	39.53	700.8	614.4	4725	44.42	1420
2.015	1.980	2.151	39.34	701.5	587.3	4720	46.44	1951
2.360	2.323	2.591	39.31	700.5	564.5	4722	47.29	2445
2.748	2.721	3.134	39.27	699.6	542.4	4715	47.65	2850
3.126	3.060	3.735	39.26	700.3	528.0	4725	47.65	3151
3.489	3.296	4.425	39.29	700.6	520.3	4710	47.66	3348
3.928	3.533	5.593	39.32	700.7	516.3	4716	47.68	3464

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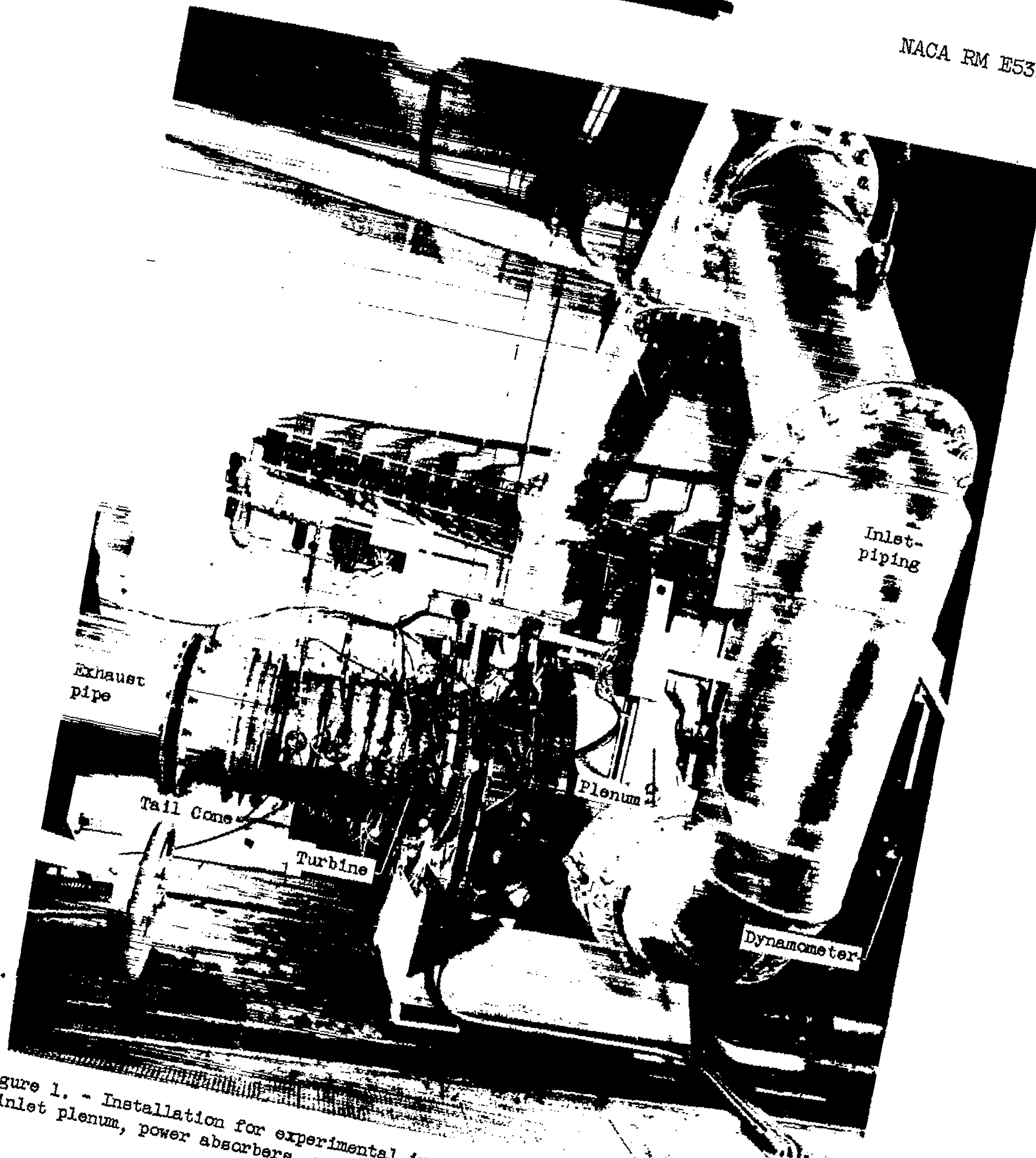
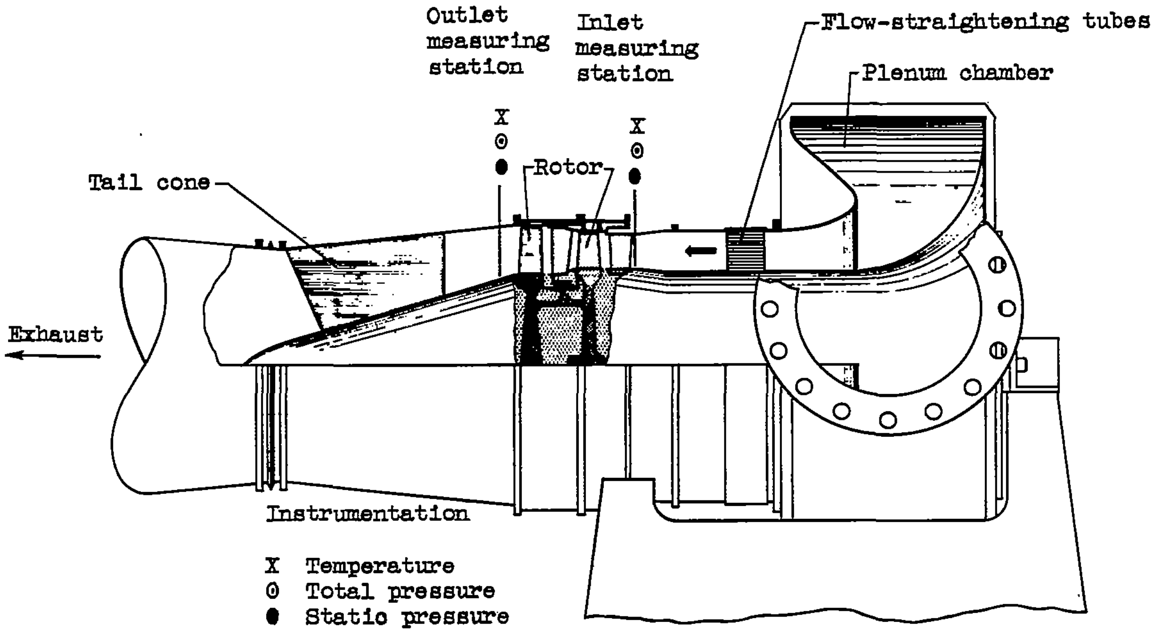
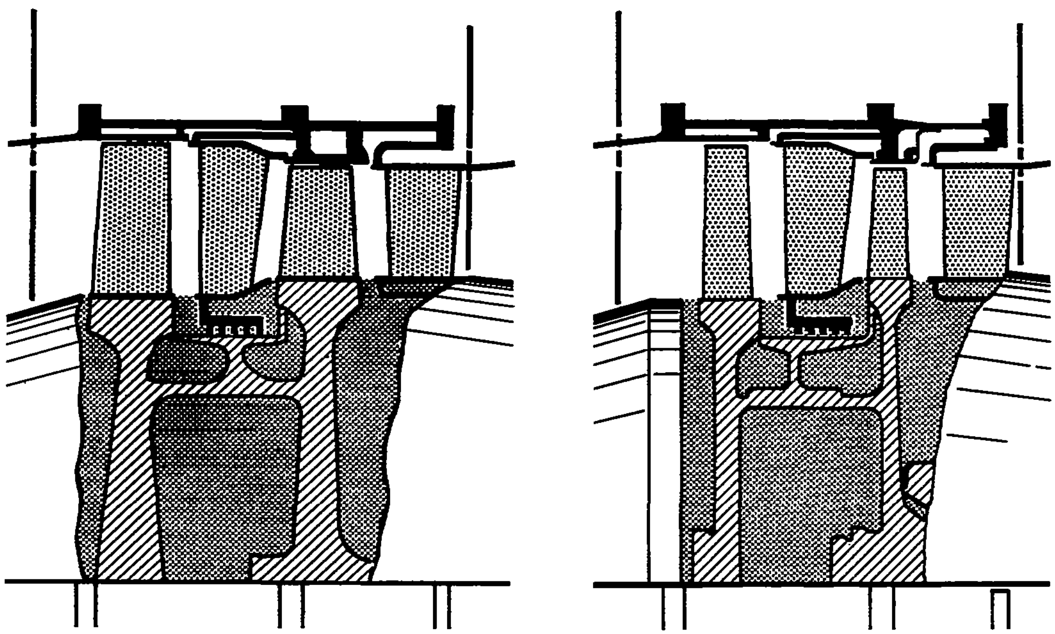


Figure 1. - Installation for experimental investigation of J73 two-stage turbine showing inlet plenum, power absorbers, and instrumentation.



(a) Over-all turbine setup.



(b) Turbine with standard rotor blades. (c) Turbine with reduced-chord blades.

Figure 2. - Schematic diagram of turbine assembly and instrumentation.

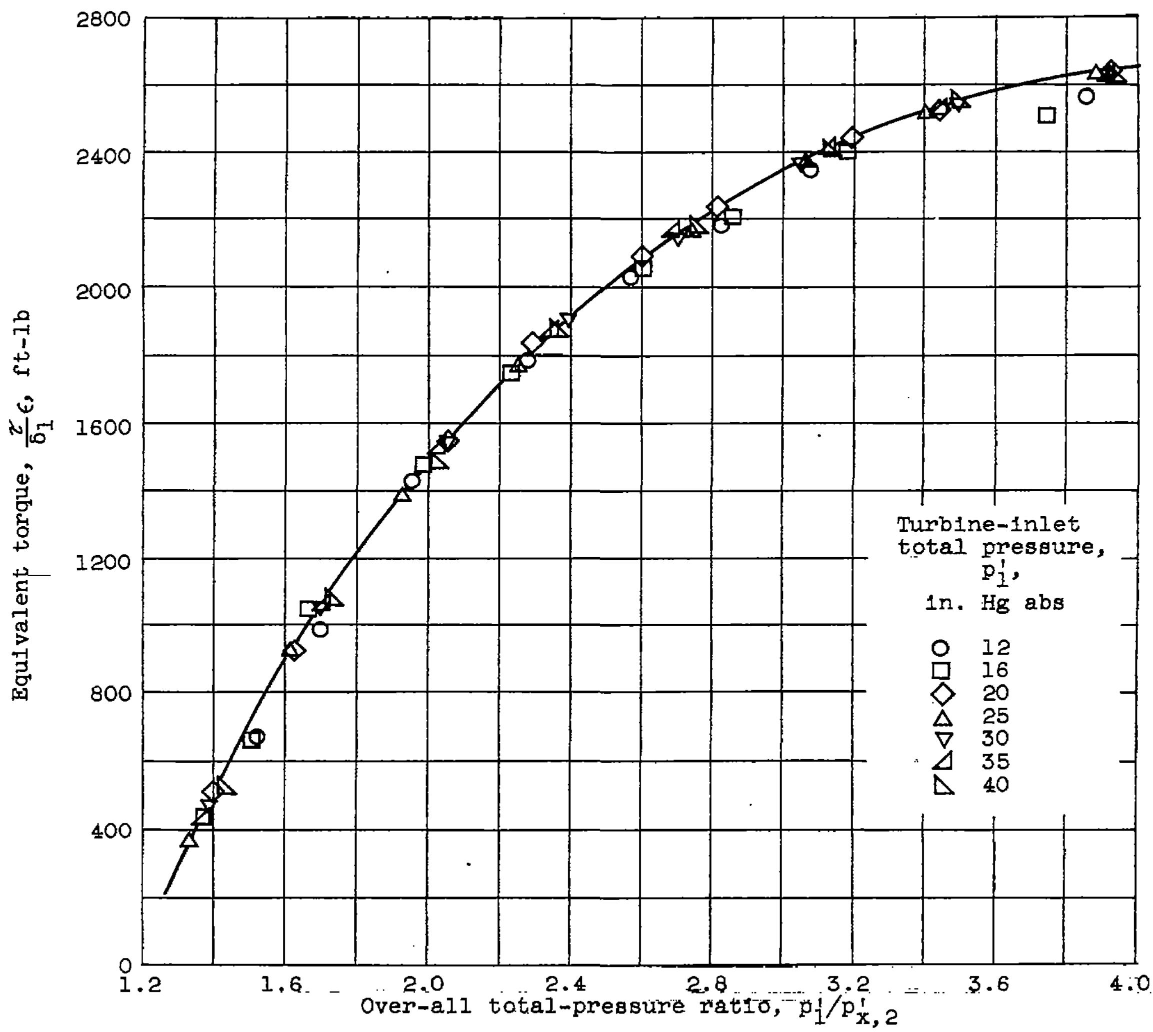


Figure 3. - Variation of equivalent torque output with over-all total-pressure ratio for J73 multistage turbine with reduced-chord rotor blades at design speed and various turbine-inlet total pressures. Turbine-inlet temperature, 700° R.

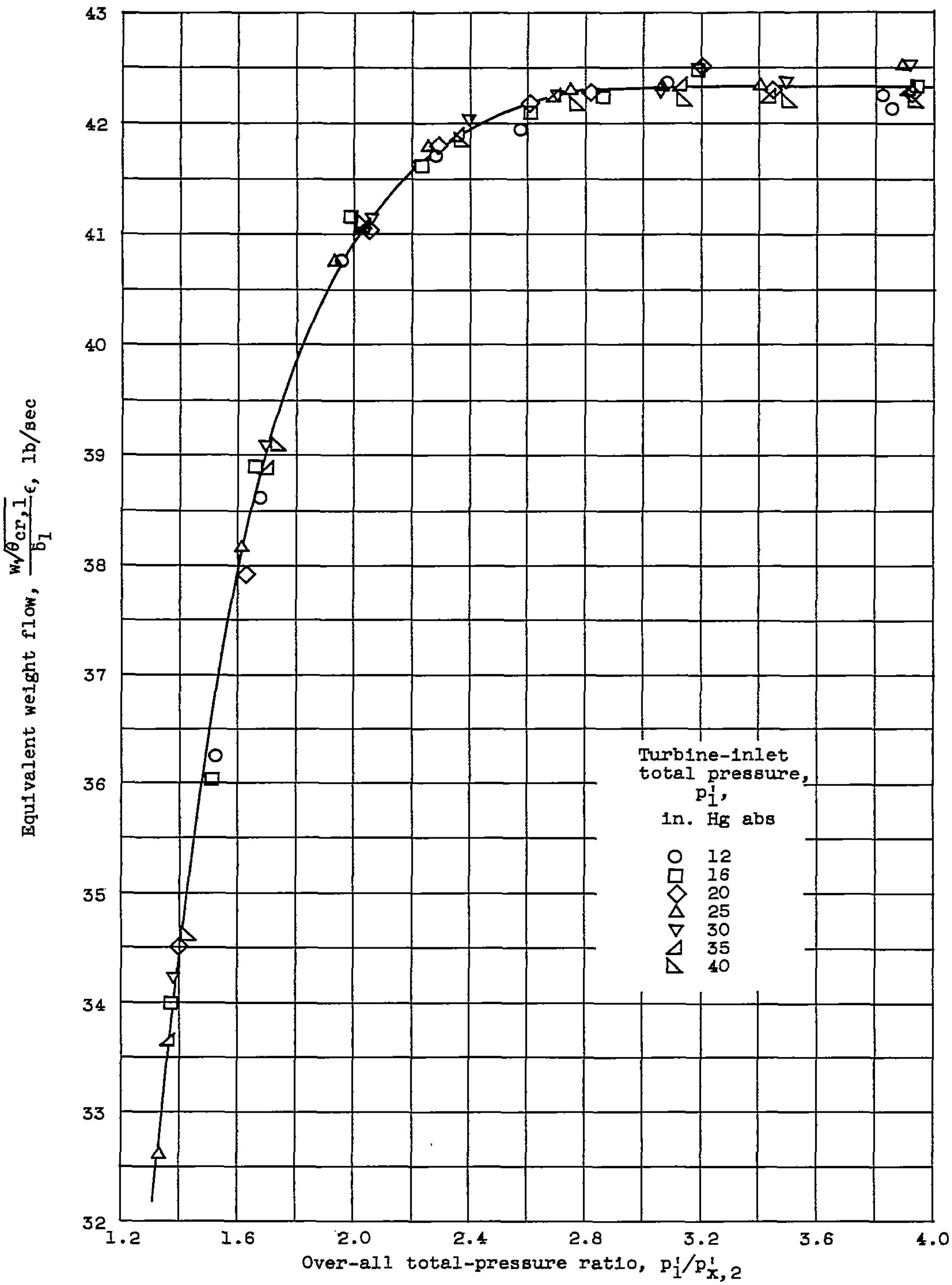


Figure 4. - Variation of equivalent air-weight flow with over-all total-pressure ratio for J73 multistage turbine with reduced-chord rotor blades at design speed and various turbine-inlet pressures. Turbine-inlet temperature, 700° R.

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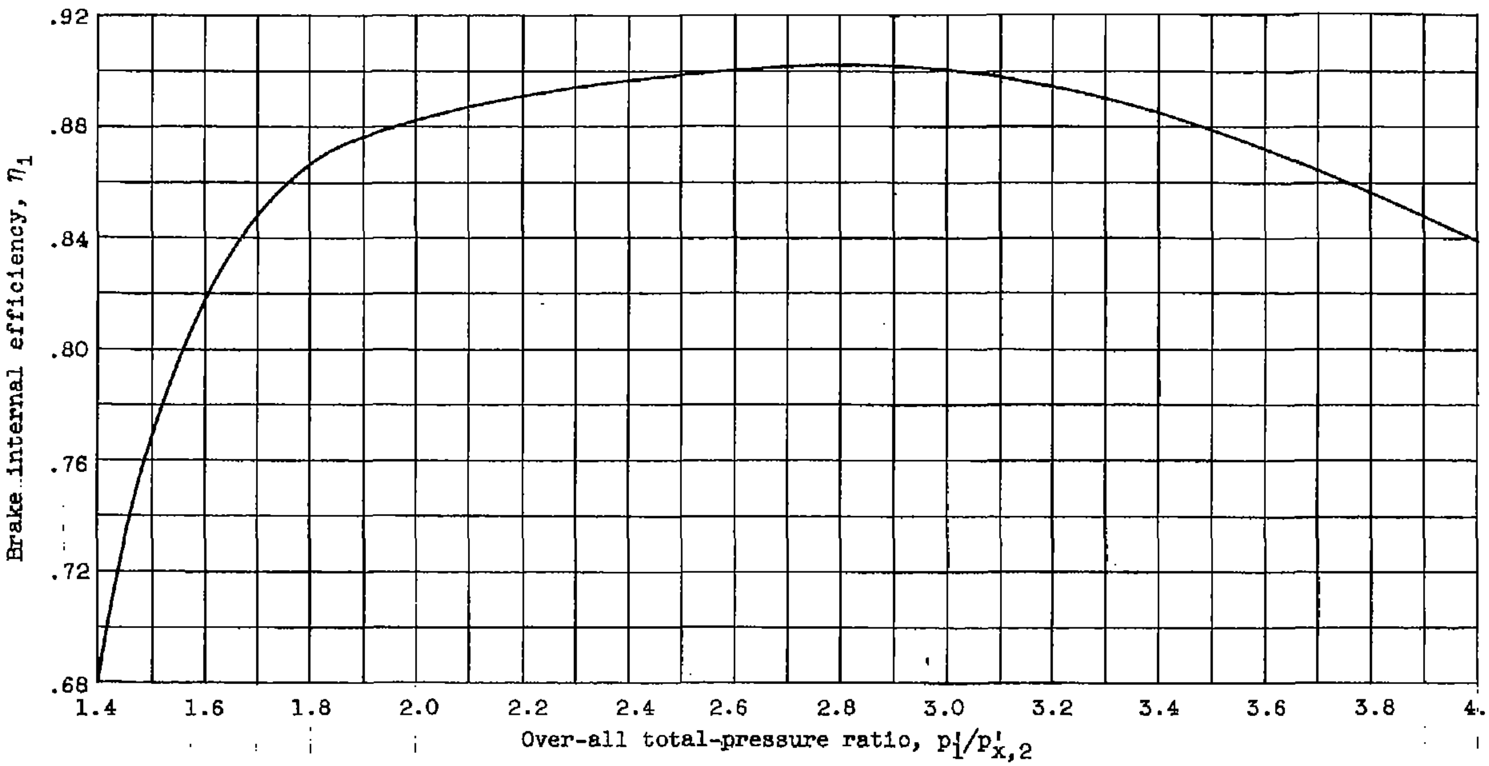

Figure 5. - Variation of over-all brake internal efficiency with over-all total-pressure ratio for J73 multistage turbine with reduced-chord rotor blades at design speed. Turbine-inlet temperature, 700° R.

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